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Guidelines for Preparation of a Probable Hydrologic Consequences Determination (PHC)

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PREFACE

This volume is one of three that address the requirements of Public Law 95-87 (the Act) and its promulgated regulations related to the protection of the hydrologic balance on and adjacent to surface coal mines. This volume contains Guidelines for Preparation of a Probable Hydrologic Consequences Determination (PHC). It supersedes the document published by the Office of Surface Mining Reclamation and Enforcement (OSM) in May 1980 entitled "Coal mining and Reclamation Operations, Parts 1 and 2, Determination of the Probable Hydrologic Consequences and the Statement of the Results of Test Borings or Core Samplings."

Another volume contains Guidelines for Preparation of a Cumulative Hydrologic Impact Assessment (CHIA). These guidance documents suggest processes and illustrations that applicants and regulatory authorities may use to prepare the required PHC and CHIA. A third volume contains appendices with supporting information for the PHC and CHIA volumes. In addition to the appendix volume, the PHC and CHIA volumes each include appendices specific to the respective document.

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INTRODUCTION

The purpose of this document is to provide an example process to applicants for mining permits and their consultants as to the kind and amount of baseline information that should be gathered, the methods that may be applied to analyze the information, and a format for presenting the PHC determination to the regulatory authority in the mine permit application.

Specifically, this document provides guidance for:

1. Identifying, collecting, and analyzing the geologic and overburden information necessary to predict the impacts of the proposed operation on the water resource of the mine and adjacent areas.

2. Identifying, collecting and analyzing the surface-water, ground-water, and geomorphic baseline information needed for preparation of a PHC determination.

3. Selecting methods the mine operators and their consultants may use to predict impacts on the quality and availability of surface- and ground-water resources.

4. Documenting the PHC determination in the permit application package.

This is an advisory document and should not be construed as being regulatory in any way. No limits or conditions are imposed except those specified by the Act itself, the promulgated Federal regulations, and approved State programs. Because the document has nationwide application, the guidance is necessarily general in nature. It is suggested that the regulatory authority develop State-specific guidelines, using the PHC process herein as a framework. In this way, the guidance would better address specific local conditions and problems.

CHAPTER I

STATUTORY AND REGULATORY REQUIREMENTS FOR DETERMINATION OF PROBABLE HYDROLOGIC CONSEQUENCES

A primary purpose of the Surface Mining Control and Reclamation Act of 1977, 30 U.S.C. 1201 et seq. (the Act), is "to protect society and the environment from the adverse effects of surface coal mining." In particular, the Act stresses protection of the hydrologic balance. Sections 507(b)(11), (b)(14), and (b)(15), 508(a)(5) and (a)(13), 510(b)(3), 515(b)(10), 516(b)(4), (b)(9), and (b)(12), 517(b)(2), and 717 of the Act set forth the main hydrologic and geologic requirements for permitting, mining, and reclaiming a surface coal mining operation. Sections 507 through 510 specifically address application requirements, reclamation plan requirements, performance bonds, and permit approval or denial, respectively. The regulations implementing these sections of the Act are found in 30 CFR Part 780 for surface mines and 30 CFR Part 784 for underground mines. The underground mine requirements are generally analogous to those for surface mines and will not be specifically discussed or referred to in this document.

Section 507 of the Act sets forth the permit application requirements. Hydrology is specifically addressed in Section 507(b)(11), which states:

> The permit application shall be submitted in a manner satisfactory to the regulatory authority and shall contain, among other things * * * (11) a determination of the probable hydrologic consequences of the mining and reclamation operations, both on and off the minesite, with respect to the hydrologic regime, quantity and quality of water in surface- and ground-water systems, including the dissolved and suspended solids under seasonal flow conditions, and the collection of sufficient data for the minesite and surrounding areas so that an assessment can be made by the regulatory authority of the probable cumulative impacts of all anticipated mining in the area upon the hydrology of the area and particularly upon water availability; Provided, however, That this determination shall not be required until such time as hydrologic information on the general area prior to mining is made available from an appropriate Federal or State agency: Provided, further, That the permit shall not be approved until such information is available and is incorporated into the application.

Thus, two separate hydrologic evaluations are required before the regulatory authority may issue a permit: a determination of the "probable hydrologic consequences of mining and reclamation both on and off the minesite," which OSM regulations term the "PHC determination" (PHC), and an assessment of the "probable cumulative impacts of all anticipated mining," which OSM regulations term the "cumulative hydrologic impact assessment" (CHIA).

The CHIA is an assessment made by the regulatory authority on the "cumulative impact area," a broad area which encompasses all "anticipated mining." Sections 780.21(c) and 780.21(g) of OSM's Permanent Program Regulations set forth the requirements for the CHIA which ultimately must be adequate to allow the regulatory authority to determine whether the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area. The CHIA is based, in part, on the data and conclusions provided by the PHC determination. The PHC is an assessment prepared by the applicant and submitted as part of the permit application. The area addressed in the PHC is narrower than that of the CHIA. OSM's regulations interpret the language in Section 507(b)(11) of the Act, which refers to the consequences of mining "both on and off the minesite," to mean that the PHC must cover the permit area and the area adjacent to the mine as defined in 30 CFR 701.5.

Part 780 of OSM's Permanent Program Regulations set forth minimum requirements for permit applications. Responsibility for the various elements of the permitting process are divided between the applicant and the regulatory authority. Figure I-1 illustrates this division of responsibility with respect to environmental protection issues. In brief, the applicant must provide in the submitted application all necessary information, analyses, and plans to demonstrate that the operation has been designed to minimize impacts to the hydrologic balance, and so that the regulatory authority can prepare the necessary findings relative to AVF's (west of the 100th meridian) and CHIA's prior to making the permitting decision.

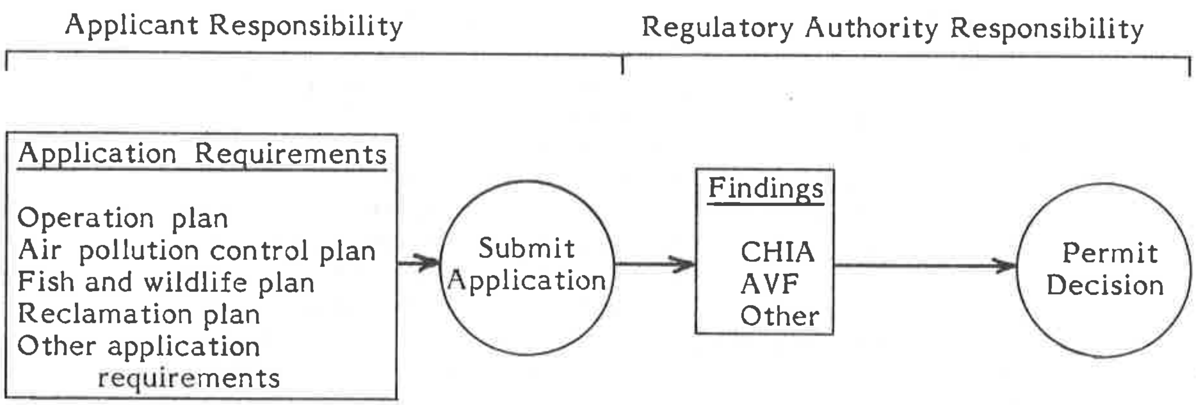

Figure I-1.--Responsibility in permitting process.

The PHC is one of several requirements related to the protection of the hydrologic balance. Others are baseline information, hydrologic reclamation plan, and surface- and ground-water monitoring plans. All these requirements are presented by the regulations as part of the mine reclamation plan. The PHC determination plays an integral role in the process set up by the Act and the regulations to protect the hydrologic balance from the deleterious effects of coal mining. It is an important element in the development of the CHIA, the hydrologic reclamation plan, and the surface- and ground-water monitoring plans. For further discussion of OSM's hydrology and geology regulations, including a discussion of the requirements of the PHC determination, see the preamble to the final hydrology and geology rules (48 Federal Register 43956, September 26, 1983).

OSM's Permanent Program Regulations set forth the minimum baseline hydrologic and geologic information upon which the PHC must be based. The regulatory authority has the authority to require additional information when the site-specific hydrologic and geologic conditions so indicate. The regulations also require the applicant to make specific findings in the PHC (780.21(f)(3)), and further compel the applicant to address in a hydrologic reclamation plan (780.21(h)) any potential adverse hydrologic consequences identified in the PHC by delineating in that plan the steps that the applicant will take to prevent or remedy such adverse impacts. In addition, the regulations require the applicant to develop surface- and ground-water monitoring plans (780.21(i) and 780.21(j)) based upon the PHC determination and other relevant information in the permit application.

CHAPTER II

THE PHC PROCESS

A permit application must contain, among other things, an operation plan and reclamation plan. The operation plan (mining plan) is a description of the proposed mining operation to be conducted during the life of the mine. The reclamation plan must show how the applicant intends to comply with the environmental protection performance standards of the Act and the regulations. Minimum requirements for this plan are detailed at 30 CFR 780.18 through 780.37.

The reclamation plan must contain hydrologic and geologic information sufficient to characterize the hydrologic system prior to mining and to identify potential impacts of that system as a result of the proposed mining operations. Minimum requirements for hydrologic and geologic information are found at 30 CFR 780.21 and 780.22, respectively. Specific types of hydrologic information required are baseline ground water, surface water, and supplemental information, baseline cumulative impact area information, alternative water source information, a probable hydrologic consequences determination, a hydrologic reclamation plan, a ground-water monitoring plan, and a surface-water monitoring plan. In addition, a cumulative hydrologic impact assessment must be prepared by the regulatory authority and made part of the application. Note that the hydrologic reclamation plan is a subpart of the overall reclamation plan and, for discussion purposes here, these two plans are considered to be distinct and separate plans. Also note that the hydrologic reclamation and the hydrologic monitoring plans are considered to be hydrologic information by the regulations and will be referred to as such in this document.

The PHC and CHIA are commonly thought to be the most important elements of the hydrologic information required in an application. However, as presented in the regulations, they are only two of several specific types of information required, and they are not given superior importance over the others. Nonetheless, they are concepts unique to this Act and, therefore, have been the focus of attention. It is important that the applicant understand the relationship of the PHC and CHIA to the other informational elements, and the specific function of each element. Therefore, this guidance document is not just about the PHC as the title would indicate, but it addresses all the hydrologic and geologic information types referred to in 780.21 and 780.22.

The general relationship of the parts of the application related to environmental protection was presented in the previous chapter with figure I-1. That figure shows that the applicant is responsible for submitting a complete application containing certain specific plans to the regulatory authority, and that the regulatory authority is then responsible for making AVF and CHIA evaluations and findings prior to approving a permit. Information in the submitted application provides the basis for the AVF and CHIA evaluations. Guidance for AVF and CHIA evaluations is provided in other documents (Office of Surface Mining Reclamation and Enforcement, 1983, 1985).

Figure II-1 shows a process for preparing the required elements of hydrologic and geologic information for the permit application, and the relation of those elements to each other. This process will be referred to as the PHC process,

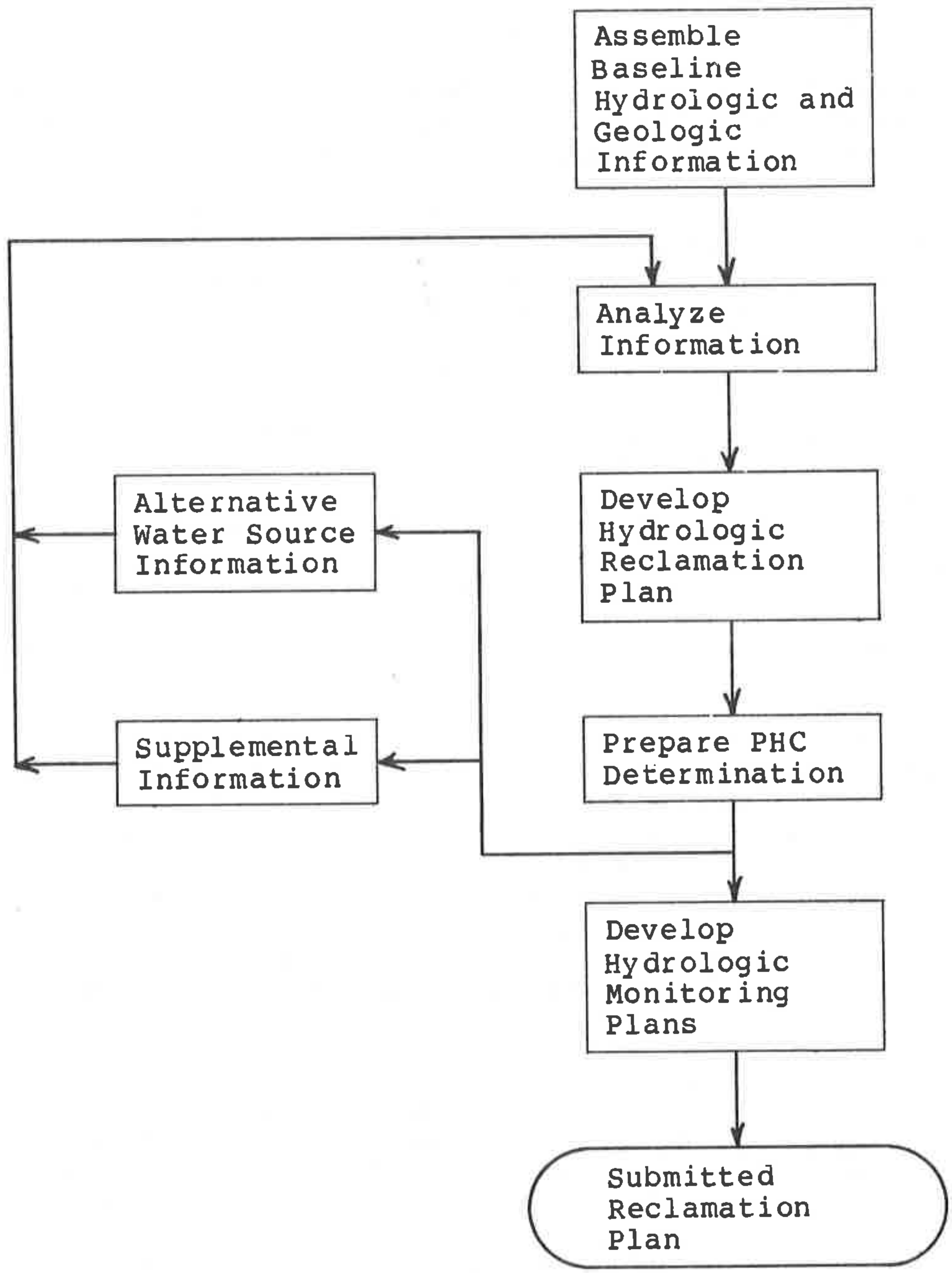

Figure II-1.--Flow diagram of the PHC process.

although the PHC determination is only one of the process elements. The total process involves information gathering, information analysis, and reclamation and monitoring planning. Basically, the process is one of identifying potential adverse impacts of the proposed operation on the hydrologic balance of the permit area and adjacent areas, developing a hydrologic reclamation plan to minimize the impacts, reevaluation of the impacts under the implemented hydrologic reclamation plan, and, finally, developing surface- and ground-water monitoring plans to verify the adequacy of the overall reclamation plan through bond release.

The PHC concept, as presented by the Act and the regulations, encompasses a dual role of problem (potential adverse impacts) identification and impact analysis. Information analysis is the basis of both roles. The Act at 507(b)(11) refers to the PHC as a "determination of the probable hydrologic consequences of the mining and reclamation operation * * *." This suggests that the PHC conclusions are those impacts predicted to be unmitigated (minimized but not eliminated) after the remedial measures of the reclamation plan have been applied. However, the regulatory requirements for the hydrologic reclamation plan states, "The plan shall specifically address any potential adverse hydrologic consequences identified in the PHC determination * * * " (780.21(h). Regulatory requirements for supplemental and alternative water source information (780.21(b)(3) and 780.21(e)) use similar phraseology to require those actions to be invoked on the basis of the PHC determination, which therefore must be made prior to these actions. This suggests an iterative procedure of analysis, application of mitigative measures, then reanalysis, as indicated by figure II-1.

The first process step is to gather baseline information. The minimum information required is specified at 780.21(b) and 780.22(b). Additional information may be needed, depending on results of the initial analysis and the requirements of the regulatory authority. This information should be sufficient to allow the applicant to describe the hydrologic system and establish premining (relative to the proposed mine) parameter values (i.e., state of hydrologic balance), from which to predict probable impacts. Baseline information requirements are discussed more fully in Chapter III.

The next step is an initial analysis of the baseline information. The baseline information is analyzed to determine the critical functions of the particular hydrologic system, to identify parameters that may be adversely affected by the mining, and to establish their premining values. Both surface- and ground-water parameters must be considered. The level of analysis necessary depends on the complexity of the hydrologic system, the importance of the water resource, and the specific requirements of the regulatory authority. Analysis methods that may be used are discussed in Chapter IV. The use of a particular methodology and level of analysis should be supported and justified in the documentation of the process.

The third step in the process is to develop a hydrologic reclamation plan that details the steps that the applicant will take during mining and reclamation periods to minimize disturbances to the hydrologic balance within the permit and adjacent areas and to prevent material damage outside the permit area. This plan must specifically address any adverse impacts indicated by the analysis conducted in Step 2 by indicating the preventive and remedial measures to be applied. Specific requirements for this plan are detailed at 780.21(h).

At the next step, the hydrologic system is reanalyzed with the proposed hydrologic reclamation plan superimposed. This analysis should predict the magnitude of impacts to be expected after the preventive and remedial measures have been applied. The results of this analysis are considered to be the required PHC determination. The specific findings that this analysis must address are detailed at 780.21(f) and are repeated here. The analysis must address:

1. Whether adverse impacts may occur to the hydrologic balance.
2. Whether acid-forming or toxic-forming materials are present that could result in the contamination of surface- or ground-water supplies.
3. Whether the proposed operation may proximately result in contamination, diminution, or interruption of an underground or surface source of water within the proposed permit or adjacent areas which is used for domestic, agricultural, industrial, or other legitimate purpose.
4. What impact the proposed operation will have on (A) sediment yield from the disturbed area, (B) acidity, total suspended and dissolved solids, and other important water-quality parameters of local impact, (C) flooding or streamflow alteration, (D) ground-water and surface-water availability, and (E) other characteristics as required by the regulatory authority.

The level of analysis used should be consistent with the complexity of the hydrologic system and the issues involved, but, in most cases, this analysis will be more detailed and rigorous than the initial analysis conducted at Step 2. The analysis and findings should focus on the specific parameters identified earlier as being particularly susceptible to adverse impacts, and must consider seasonal fluctuations of parameter values. Selection of appropriate analytical methods is discussed in Chapter IV. Again, the use of a particular methodology and level of analysis should be adequately supported and justified in the documentation of the process.

If the Step 4 predictions indicate that some adverse impacts remain after the remedial actions outlined in the proposed hydrologic reclamation plan have been applied, another iteration of data collection and analysis may be necessary. Collection of supplemental information to better define the hydrologic system with respect to the impacted parameters may be necessary. This must inclu information necessary, including aquifer pump tests, floodflow analyses, et c so that the applicant can appropriately modify the hydrologic reclamation pl demonstrate that the predicted impacts will be minimized. If the Step 4 a predicts adverse impacts to a water source being used for any legitimate p then the applicant must also provide information on alternate sources of wat

When the analysis shows and the applicant can demonstrate that the p impacts have been minimized, then surface- and ground-water monitorin must be developed. The objective of these plans is to verify the pr parameter values during mining and reclamation through bond release. Th should incorporate as many of the baseline information collection sites as p to provide continuity and to measure trends from premining to post conditions. Specific requirements of the monitoring plans are detailed at 7 and 780.21(j).

A final item, not shown in figure II-1, is the documentation of the total PHC process. This is accomplished by preparing a report of all the steps involved. The report then becomes a part of the permit application package to be submitted to the regulatory authority. Adequate analysis and documentation of the findings listed in Step 4 constitutes the required PHC determination. This report and an example outline are discussed in Chapter V.

CHAPTER III

BASELINE INFORMATION REQUIREMENTS

Baseline information comprises the body of data needed to define the site-specific conditions prior to mining. It must include parameters that describe the hydrologic balance under seasonal flow conditions. The regulations require the applicant to obtain sufficient baseline hydrologic and geologic information to make a PHC determination, which, in turn, is used to develop a hydrologic reclamation plan, surface- and ground-water monitoring plans, and to provide the regulatory authority with information for preparation of a CHIA. Baseline information provides a starting point from which to make the predictions required in the PHC determination, and with which to compare potential hydrologic changes caused by mining.

The regulations outline specific requirements for each of these determinations, assessments, and plans. Taken together, the specific requirements refer to a wide range of hydrologic concerns, including flooding and streamflow changes, seasonal variations in flows, sediment yield, drainage control, total suspended solids, total dissolved solids, toxic and acid drainage, water availability, water use, restoration of recharge capacity, disturbance to the hydrologic balance, material damage prevention, and compliance with Federal and State water quality laws. The information base must include enough parameters to sufficiently describe site-specific conditions so that these specified portions of the hydrologic balance can be adequately addressed.

Thus, an understanding of the total hydrologic system is necessary. This implies a need for data and information on ground-water recharge and discharge areas, ground-water flow rates, surface-water peak and low flow rates and associated TDS and TSS concentrations, and sediment yields, as well as the other minimum information required by the regulations (such as pH, total manganese, total iron). Additional (supplemental) information may be needed to further evaluate and plan remedial actions for any potential adverse impacts indicated by the initial PHC evaluation.

Assembly of the necessary baseline information is a two-step process. First, existing information should be assembled and evaluated for usefulness and adequacy in PHC determination. The evaluation should explore the accuracy of the information and its suitability for transfer to the necessary sites. Secondly, on the basis of this evaluation, a plan should be developed for obtaining additional data needed to conduct the PHC determination. This may involve additional field sampling and analysis.

The time of year and frequency of water sampling should be specified by the regulatory authority on the basis of when critical concentrations are expected to occur. Generally speaking, total constituents (that is, total suspended solids and total iron and manganese) predominantly are transported during high flows, when surface runoff and erosion take place. By contrast, dissolved constituent concentrations in perennial and intermittent streams generally are highest during low flows, when streamflow is predominantly derived from ground-water discharge. Both these conditions must be covered in the baseline data program to adequately

allow for seasonal variation. The more frequently data are collected, the better the hydrologic balance can be defined. If an important surface-water resource is to be protected or if streamflow is highly variable, daily discharge determinations may be needed. Water-quality sampling frequency should be adjusted so that annual discharge cycles of high, normal, and low flows are sampled.

GEOLOGIC AND OVERBURDEN INFORMATION

The baseline geologic data should include description of the geology of the proposed permit and adjacent areas and must include cross sections, maps, and plans. These data may be gathered from geologic literature and from various analyses of samples collected from test borings, drill cores, or fresh, unweathered, uncontaminated samples from rock outcrops from the permit area. These analyses should result in stratigraphic logs showing characteristics of each stratum, chemical analyses identifying strata that may contain acid- or toxic-forming or alkaline-producing material, and chemical analyses of the coal seam for acid- or toxic-forming materials, including total sulfur and pyritic sulfur.

Overburden may possess a wide variety of chemical and physical properties that can adversely affect water quality. Premining assessment of overburden properties should provide important information that may indicate potential water quality and revegetation problems during mining and reclamation. Information obtained from the assessment can be used to design mining and reclamation plans that will result in environmentally acceptable and cost-effective operations. 30 CFR 780.22 requires the applicant to submit geologic information in sufficient detail to identify all potentially acid, toxic-forming, or alkaline strata to be disturbed by mining.

Premining assessment of overburden is similar to a coal exploration program, but the primary goal is identification of undesirable strata within the overburden rather than evaluation of the coal resource. In addition, the premining assessment should also attempt to identify favorable overburden strata that can be used to neutralize potentially acidic materials or as a topsoil substitute or supplement. Because of their similarities, it may be possible to integrate coal exploration and premining overburden assessment programs.

Prior to designing an overburden assessment program, existing data sources on the geology and hydrology of the permit and surrounding areas should be evaluated. In a given permit area, only a limited number of parameters may be of concern. Selected factors can be evaluated for each permit area to determine which overburden constituents pose the greatest potential water quality problems. Criteria for selecting parameters are given in table III-1. This table identifies parameters of general concern in relation to the anticipated chemical environment in spoils and the projected postmining uses of water affected by mining. Experience in previous reclamation at comparable mining operations can be particularly useful. This information can be utilized to design drilling and sampling programs and in selecting overburden parameters for analysis.

Table III-1.

CRITERIA FOR SELECTING PARAMETERS IN OVERBURDEN FOR PREDICTION OF POTENTIAL WATER QUALITY IMPACTS

Parameters	Potential Chemical Environment in Spoils[1]		Projected Uses of Water Affected by Mining[2]		
	Acidic	Alkaline	Domestic Supply	Agriculture	Freshwater Aquatic Life
pH	X	X	X	X	X
Acid-base account	X	X	X	X	X
Soluble salts	X	X	X		
Electrical conductivity	X	X	X		
Sodium adsorption ratio		X		X	
Cation exchange capacity		X		X	
Chloride (Cl)			X		X
Fluoride (F)			X		
Nitrate (NO_3)			X		
Phosphate (PO_4)					X
Sulfate (SO_4)	X	X	X		
Aluminum (Al)	X			X	
Ammonia (NH_3)			X		X
Antimony (Sb)			X		
Arsenic (As)	X		X	X	
Boron (B)		X		X	
Cadmium (Cd)	X		X		X
Calcium (Ca)		X	X	X	
Chromium (Cr)	X		X		X
Copper (Cu)	X		X		X
Iron (Fe)	X		X		X
Lead (Pb)	X		X		X
Magnesium (Mg)		X	X	X	
Manganese (Mn)	X		X		
Mercury (Hg)			X		X
Molybdenum (Mo)		X		X	
Nickel (Ni)	X			X	X
Selenium (Se)		X	X		
Sodium (Na)		X	X	X	
Zinc (Zn)	X		X		X
Potential sediment			X		X

1"X" Indicates parameters typically associated with acidic or alkaline condtions.
2"X" Indicates parameters for which generally recognized water-quality criteria have been extablished; other parameters for which criteria have not been established may also cause water quality problems in particular cases.

Adapted from: State of the Art and Guidelines for Surface Coal Mine Overburden Sampling and Analysis, Phase II Report: Recommended Guidelines, Colorado School of Mines Research Institute, Golden, Colorado, 1981.

Overburden Sampling

The principal objective of overburden analysis is to delineate the spatial occurrence of potentially acid or toxic material that can adversely affect water quality or vegetation. When recognized, this material can be handled and placed during mining and reclamation to minimize impacts to the hydrologic system. Strata capable of neutralizing or isolating acid and toxic material or material suitable for sustaining vegetation can also be identified from overburden analysis. The intensity of sampling necessary to characterize overburden properties varies widely throughout the country and is dependent on such factors as:

1. Stratigraphic variability, both vertical and horizontal.
2. Geologic structure.
3. Geochemical variability, both vertical and horizontal.
4. Topography.
5. Mining method.
6. Local hydrologic conditions.
7. Availability of overburden data from adjacent or nearby sites.
8. Historical water quality data associated with past mining.

An initial assessment of overburden properties can often be obtained from consideration of broad basin or subbasin characteristics. Surface mining provinces have been defined for the Appalachian and Midwestern coal fields (Smith, Grube, and others, 1974; Smith, Sobek, and others, 1976). Boundaries and characteristics of these provinces are necessarily generalized and exceptions often occur. Province concepts, however, tend to provide useful guidelines for sampling and interpretation. For example, Province 1, encompassing southern West Virginia, is broadly defined as having overburden rocks that are low in total sulfur and acid potential, low in neutralizers, and resistant to weathering. As a result of these characteristics, acid or toxic drainage occurs infrequently in this area. Province 3, comprising northern West Virginia, is characterized by high sulfur, alkaline, fine-grained overburden rocks. Substantially greater potential exists for acid or toxic discharges to occur in this province. State regulatory authorities and many operators are familiar with province characteristics and use this concept for preliminary definition of overburden sampling needs.

Some regulatory authorities have further refined the province concept to identify specific coal seam overburdens as acid or toxic on the basis of historical performance or regional studies. The identified materials nearly always exhibit acid or toxic drainage when improperly controlled.

Collection of overburden samples is accomplished most efficiently during initial exploration activities or during geologic and hydrologic baseline data collection. Continuous rotary drilled cores provide the maximum useful information for overburden sampling in consolidated rock. Unconsolidated materials are typically sampled by split barrel (split spoon) or Shelby tube methods. Weakly consolidated rocks may require special soft sediment core barrels or other methods. Appropriate drilling techniques are discussed in various handbooks and manuals (Acker, 1974; Colorado School of Mines, 1981; Barrett, 1980). Geophysical

logs can provide supplemental hydrologic and stratigraphic information. Samples collected from drill cuttings or fresh, unweathered samples obtained from highwalls and outcrops are also suitable for overburden analysis, although less information may be obtained. Such features as ground-water flow zones, fractures, joints, bedding planes, lighologic contacts, and chemically or physically weathered strata usually cannot be observed in highly disturbed samples such as drill cuttings but can frequently be determined from inspection of rock cores.

Spacing of overburden sample locations is determined largely by area and site specific conditions. Recommendations for drillhole spacing range from as close as 200 feet (Dollhopf and others, 1981) to a maximum of about two-thirds of a mile (Sobek and others, 1978). Other sources (Colorado School of Mines, 1981) recommend at least one drillhole for each 160 acres arranged in a grid pattern. Complex or variable geochemical and stratigraphic conditions necessitate more intensive sampling than where overburden properties are consistent over large areas. Many regulatory authorities have developed informal guidelines for overburden drillhole spacing on the basis of their knowledge of area conditions.

Examination of fundamental overburden properties is frequently useful in identifying potentially acid or toxic materials. Lithology, color, and visible mineral assemblages of iron disulfides, salts, or carbonates have been demonstrated to be useful selection criteria for delineating sampling zones (Sobek and others, 1978). Sampling intervals are determined by dividing the overburden column into lithologic units down to about 10 feet below the lowest coal seam to be mined (Colorado School of Mines, 1981). Thin horizons less than 1 to 2 feet in thickness may be composited into overlying or underlying rock units unless special properties or handling requirements are anticipated. Each lithologic unit is subdivided to represent maximum sample intervals of about 5 feet to identify vertical changes in geochemical properties (Sobek and others, 1978). For underground mines, sampling of 1-foot intervals of roof and floor materials immediately adjacent to the coal is recommended (Sobek and others, 1978). Only the roof, coal, and floor require sampling for an underground mine unless the operator anticipates exposing other strata during mining. Step-by-step procedures for collecting and sampling cores, rock chips, and soil are provided (Sobek and others, 1978).

Analytical Methods

Characterization of acid or toxic potential of overburden material is accomplished by either of two methods including a technique known as acid/base accounting (Smith and others, 1982; Sobek and others, 1978) or leaching tests (Caruccio and others, 1977, 1981, 1982; Caruccio, 1984; Geidel, 1979). Additional analyses for salinity, trace elements, or other parameters may be required or recommended by regulatory agencies. These supplementary tests are commonly requested for mines in the Western States and the specific parameters are most appropriately determined on a site-specific basis.

Acid/base accounting is utilized nationwide to assess acid or toxic potential and consists of the following three fundamental measurements:

1. pH of a pulverized sample mixed with distilled water to the consistency of a thin paste.

2. Measurement of total disulfide content (mainly pyrite).

3. Measurement of total neutralization potential.

Paste pH is a measure of the sample's immediate acidity or alkalinity and reflects current geochemical conditions. Samples with a paste pH of 4.0 or less are classed as acid/toxic regardless of the pyrite and neutralizer balance (Smith and Sencendiver, 1982; Sobek and others, 1978). Solubility and mobility of many trace elements and metals in water are strongly dependent on pH. At pH 4.0 or less, elements such as aluminum, copper, manganese, zinc, lead, chromium, and others can be released into ground or surface waters.

High pH levels of greater than about 9.0 may also degrade water quality. Excessive concentrations of soluble salts, sodium, selenium, boron, or other constituents may be released from spoil materials under strongly alkaline conditions. Low pH overburden materials occur principally in the Eastern and Midwestern coal fields, while alkaline conditions commonly occur in the Western States.

Maximum potential acidity is calculated from the pyrite content of the sample and the four-step chemical reaction of pyrite to acid formation (Sobek, 1978). Note that this calculated value represents the maximum or worst case scenario of acid production. The actual acid production rate and completeness of reaction cannot be estimated by this technique.

Neutralization potential measures the sum total of carbonates, alkaline earths, and bases available to neutralize acidity generated and represents the most favorable condition. Calculations of maximum potential acidity and neutralization potential are structured to equate the two measurements to a common basis for comparison. The resulting values, expressed as calcium carbonate equivalent, are compared to compute a net acid-producing or neutralizing potential. Materials exhibiting a net acid production potential of 5 tons/1,000 tons of overburden material or more as calcium carbonate equivalent are classed as toxic or potentially toxic (Smith and Sencindiver, 1982; Sobek and others, 1978; Sturm and others, 1984). The selection of stone/1,000 tons net acid production potential as the cutoff for acid or toxic material is somewhat arbitrary and was originally based on revegetation considerations. Materials with a net neutralization potential are not expected to form acid or toxic drainage.

The primary advantages of the acid/base accounting method are:

1. Short turn-around time for sample processing.
2. Low cost.
3. Relatively simple analytical procedures.
4. Results do not require sophisticated interpretation.

Application of this method to overburden handling and placement plans throughout the country has shown generally good results in eliminating or reducing adverse water quality impacts. Acid/base accounting is typically considered state of the art for overburden analysis.

The principal disadvantages of acid/base accounting are:

1. The method predicts maximum potential acidity and maximum neutralization capability and implies a 1:1 acid to base reaction. Actual acid production and neutralization release rates cannot be predicted with this technique nor can completeness of the reaction be assessed.
2. Acid/base accounting assumes all acid production is attributable to iron disulfide minerals (chiefly pyrite) and that no acid is produced by sulfate or organic sulfur forms. Recent sulfur fractionation studies of some Western overburden material have shown that about half of the total sulfur is present in organic forms and that acidity is being produced that cannot be accounted for by pyrite alone. The possible contribution of acid production from organic sulfur is a concern of several regulatory authorities and is currently being researched.
3. Measurement of neutralization potential utilizes a hot acid extract to measure carbonates and bases. Recent work in Texas suggests that this extraction procedure may overestimate neutralization potential and that a modified method may be needed.

Leaching or simulated weathering tests have been advocated by Caruccio and others (1977, 1981, 1982), Caruccio (1984), and Geidel (1979) as an alternative overburden analysis method. The procedure is designed to mimic the conditions expected to occur in regraded spoil. Samples are subjected to alternating water leaching and exposure to moist air. Leachate is collected periodically and analyzed for pH, acidity, sulfate, and any other constituents of interest. Supplemental information may also be obtained by petrographic study of pyrite morphology. Caruccio has indicated that fine-grained pyrite with a large surface area is much more reactive and likely to produce acidity than coarse-grained pyritic material (Caruccio, 1969, 1984; Caruccio and others, 1982).

Results of leachate analyses are plotted as a function of time and data evaluated as to both rate of reaction and quantity of acidity or alkalinity produced. Leaching simulations have been applied to Eastern and Midwestern minesites and are reasonably good predictors of short-term (2 or 3 years) drainage quality.

Caruccio (1984) recently suggested that acid/base accounting be used as an initial screening test for overburden samples. Materials containing a large net neutralization potential do not require further analyses. If total pyrite exceeds about 1 percent or if the net acid/base account is small, Caruccio recommended leaching tests to more accurately predict drainage quality.

The main advantages of leaching tests are summarized as follows:

1. Test methods are designed to simulate field conditions.
2. Reaction rates (kinetics) can be evaluated.
3. Leaching of overburden constituents other than acidity and alkalinity can be evaluated.

The primary disadvantages associated with leaching tests are:

1. Test time. About 2 months are required to conduct an analysis.
2. Cost of analysis.

3. Long-term predictive capability of leaching tests are uncertain.
4. Data interpretation requires more sophisticated review than the acid/base accounting method.

Supplementary tests in addition to acidity/alkalinity analyses may be required or recommended by regulatory authorities particularly in the Western States. Additional analyses are usually conducted for selected trace elements or general indicator parameters which have been determined by the regulatory authority to be of statewide or areawide importance. These may include:

1. Salinity and electrical conductivity.
2. Sodium and sodium-adsorption ratio (SAR).
3. Selenium.
4. Boron.
5. Plant nutrients, such as phosphorus and nitrogen.
6. Others.

Selection of specific supplemental analyses is based on regulatory requirements, and consideration of premining and expected postmining water use. General criteria for selecting overburden parameters based on water use are provided in table III-1. This initial list can typically be refined to a few parameters of local importance. For example, iron and manganese may contaminate domestic water supplies in Eastern States, whereas boron may affect irrigation water in Western States. Analytical methods for these determinations are contained in several laboratory and reference manuals (Berg, 1978; Page, 1972; Richards, 1954; Sandoval and Power, 1977; Sobek and others, 1978; U.S. Environmental Protection Agency, 1979).

Mine Planning

Results of overburden analyses are required as part of the geology description for mining and reclamation operations plans. These data identify acid or toxic overburden zones and are used to develop overburden handling plans and water quality controls. Exposure of overburden material to both air and water is necessary to form acid or toxic drainage. In practice, isolation of potentially acid- or toxic-producing material from air and water is usually accomplished by deep burial, by layering within the backfill, or by blending with neutralizing materials. Selection of the appropriate disposal method is based on site-specific consideration of mining methods, location of acid/toxic material in the highwall, and hydrologic conditions. Three simple examples described below illustrate different disposal methods.

Case 1.--In an Appalachian contour type surface mine, acid/toxic material is placed in the middle of the spoil profile surrounded by slowly permeable material. This eliminates contact with ground-water seepage along the pit floor and restricts the flow of water and oxygen into the toxic material.

Case 2.--In a Midwestern area surface mine, acid/toxic material is placed on the pit floor and is completely submerged when the water table is reestablished following reclamation. Even though the material is in contact with water, no oxygen is available in the saturated zone to initiate acid formation.

Case 3.--In a Western area surface mine, saline overburden is placed above the water table to minimize leaching of soluble salts into the ground-water system. The material is also buried deep enough below the ground surface to preclude capillary migration of salts into the root zone.

These brief illustrations are indicative of the variety of disposal methods available for backfilling acid/toxic spoil.

Overburden analysis is also useful for selecting strata suitable for placement in the root zone and for identifying topsoil substitutes or supplements. Regulatory criteria for determining suitability of topsoil substitutes are contained in 30 CFR 780.18(b)(4) and include parameters relating to thickness, quantity, and location of the material, texture (grain size), pH, and coarse fragment content. The regulatory authority may also require supplemental chemical and physical tests, greenhouse tests, or field trials. These supplemental tests vary depending on the proposed substitute and regulatory concerns and may include selected major and micro plant nutrients, such as phosphorus and zinc, cation exchange capacity, plant available water holding capacity, or other parameters. Overburden characteristics favorable for plant growth include near neutral pH (about 6.0 to 7.5), net neutralization potential, moderate to high levels of plant nutrients, and intermediate texture.

Provisions for Waivers

Section 507(b)(15) of the Surface Mining Control and Reclamation Act (SMCRA) allows the regulatory authority to waive the application requirement for overburden analysis upon finding that such a requirement is unnecessary. Sections 780.22(d) and 784.22(d) of OSM's permanent program interpret SMCRA to allow waivers when equivalent information is available to the regulatory authority in a satisfactory form. Equivalent information usually consists of an overburden analysis for the same overburden sequence from an adjacent or nearby minesite. Other sources, such as published studies, may also provide the regulatory authority with sufficient information to assess overburden properties. Waiver approval must be granted in writing from the regulatory authority and must be included in the permit.

Granting a waiver for overburden analysis is considered on a case-by-case basis. Implicit in an approved waiver is a decision by the regulatory authority that the equivalent information satisfactorily identifies overburden properties for the specific minesite in question. This decision is based on consideration of several factors including regional and site geologic structure, stratigraphy, geochemistry, and hydrology. Supplemental information, such as historical water quality data associated with past mining or regional overburden studies, also provides a basis for decisionmaking.

Areas having complex geologic structure and variable stratigraphy and/or geochemistry are poor candidates for waiving overburden analysis. Under such variable conditions, little confidence can be placed in the accuracy of information

extrapolated even over short distances. Conversely, areas with relatively uniform geologic, geochemical, and hydrologic conditions are more predictable. Assessments of overburden conditions from equivalent information can be assigned a much higher degree of confidence in these areas.

The decision to grant or deny a waiver can be further substantiated by examination of historical water-quality and hydrologic data, past mining activities, and existing water uses. Overburden materials associated with specific coal seams which typically produce acid or toxic discharges should be analyzed on each new minesite. If minimal hydrologic impacts have been observed from previous mining, granting a waiver may be feasible. New operations in areas with little or no past mining or in hydrologically sensitive areas, such as lightly buffered streams, generally need a site-specific overburden analysis. Water use of the existing hydrologic system and anticipated mining impacts may also be considered. If mining will occur in proximity to water supplies, potential impacts can be most confidently assessed from onsite overburden analyses.

Overburden analysis requirements may be waived if the regulatory authority finds in writing that the collection and analysis of such data are unnecessary because other equivalent data are available. There is no concensus recommendation on extrapolating overburden data between sites or the confidence that can be placed in these projections. Smith (Sobek and others, 1978) recommended extrapolating overburden data no more than about two-thirds of a mile and has indicated that lesser distances may be necessary. This distance is based mainly on studies conducted in the Appalachian and Midwestern coal fields, where stratigraphic units are frequently discontinuous or variable over short distances. In the Western States, extrapolation of overburden data should be limited to about one-half mile (Colorado School of Mines, 1981). Although precise agreement on distances is lacking, the literature does indicate that overburden analysis can only be extrapolated over relatively small distances to accurately assess overburden conditions.

In summary, a decision to issue or deny a waiver for overburden analysis is based on an evaluation of several geologic, geochemical, and hydrologic factors and a determination that equivalent information is available. The regulatory authority must determine that the equivalent information accurately describes minesite conditions within the context of the PHC statement. Each waiver application encompasses a unique set of conditions, requiring a case-by-case consideration.

HYDROLOGIC INFORMATION

Baseline hydrologic information should describe the site-specific conditions of the hydrologic balance of the permit and adjacent areas prior to mining. Development of an adequate information base involves a search of known data sources. Before any new data are collected, a data search should be conducted and all appropriate hydrologic data should be evaluated. Information about data sources can be accessed through the National Water Data Exchange (NAWDEX), which is a national confederation of more than 400 water-oriented organizations who have listed water data availability (U.S. Geological Survey, 1980). The Office of Water Data Coordination (OWDC) of the U.S. Geological Survey has published the "Index to Water-Data Activities in Coal Provinces of the United States." The National Water Data Storage and Retrieval System (WATSTORE) contains actual

data collected by the U.S. Geological Survey on the quantity and quality of surface and ground water (Hutchinson, 1975). A water data base (STORET) is maintained by the U.S. Environmental Protection Agency (EPA), and any contributor may store his data in the system so that others may access and use it. Also, a series of reports is available (Graves, 1980) describing the coal provinces throughout the United States. These reports systematically describe available data, hydrologic conditions, mining impacts, and available hydrologic studies for each coal area. Appendix C.1 lists Federal, State, and local agencies that may have useful hydrologic data.

If this initial search does not result in an adequate information base, then field measurements and sampling may be necessary. In nearly every case, some field data collection will be necessary.

Ground Water

Minimum ground-water information requirements are stated in the regulations at 780.21(b). This information includes the location and ownership of existing wells, springs, and ground-water-fed streams, approximate rates of usage or discharge, a measure of total dissolved solids, pH, total iron, and total manganese, and depth to water in each water-bearing stratum, including the coal seam, down to and including the deepest potentially impacted stratum below the coal seam. The information must be sufficient to demonstrate the seasonal variability of measured parameters. Additional information may be required depending upon the complexity of the hydrologic system and the concerns of the regulatory authority.

Minimum baseline ground-water information requires an inventory of wells and springs near the permit area, including location, ownership, quantity, season of use, spring discharge rates, depth to water, and specified measurements of water quality. Other useful information about wells that the regulatory authority may require includes depth and diameter of wells, position of screens, drillers' logs, geophysical logs, measurements made, and hydrologists' interpretation of well-acceptance tests, description of measuring point, elevation of measuring point, periodic measurements of static water level, pumping water level, and yield. Aquifer testing may be required of suitable existing wells to complete the description of the ground-water system and its uses.

The hydrologic balance of the ground-water-flow system involves the relationship to one another of the recharge rate, the change in quantity of water stored in the system, and the rate of discharge and withdrawal from the system. Ground-water quantity, with respect to surface mining regulations, refers to the volume of water that a particular stratum or group of strata underlying the permit and adjacent areas contains (storage) and can supply (discharge) for a specified use. This volume is a function of the physical characteristics of the strata.

A zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use is called an aquifer. The volume of water that an aquifer can hold is a function of its thickness, areal extent, and the volume of void space it contains. The rate at which water can be removed from the aquifer depends on the size of the voids, how much of the aquifer is saturated, its head gradient, the rate of recharge, and whether it is confined or unconfined. The impacts of mining on the hydrologic balance of ground-water quantity depends on

which and to what degree the mining will change these aquifer characteristics and rates of recharge and discharge.

The determination of potential impacts to the ground-water quantity involves defining aquifer recharge and discharge characteristics prior to mining, estimating how the characteristics will be changed during and after mining, and then estimating to what degree those changes will affect the hydrologic balance in general, and how they will affect the amount of water that can be obtained from the aquifer, in particular. The parameters used to define ground-water movement through the permit area must be evaluated over a long enough time period to reflect the seasonal fluctuations in flow rates and water quality.

The number of ground-water evaluation sites (observation wells) needed depends on the complexity of the hydrologic system and the requirements of the regulatory authority. Two wells completed in each stratum to be characterized, One located upgradient and the other downgradient from the permit area, will usually provide adequate coverage. However, as the system complexity increases, more observation wells are necessary. For simple aquifer systems and small permit areas, it may be sufficient to extrapolate information from existing wells, but even for simple systems, at least one well should be completed in each water-bearing stratum to be characterized. An existing well can be used for sampling if it is properly completed in a stratum to be characterized, is located to reflect conditions on the permit area, and is accessible. Normally, water-level measurements and water-quality samples should be obtained at each site.

At a minimum, a description of total dissolved solids or specific conductance corrected to 25°C, pH, total iron, and total manganese must be included in the baseline data. These parameters must be sampled frequently enough to determine the fluctuation in values over the annual cycle. The regulatory authority may require analysis for other water-quality parameters.

Defining baseline geochemistry may require point measurements of water quality upgradient and downgradient from the minesite in each aquifer. The wells used for measurement should be properly completed to ensure that the quality of water in the well is representative of that in the aquifer. Because of the unique environment within the aquifer, some constituents present in water are unstable when the water is removed from the aquifer and require special techniques of collection and analysis (Wood, 1976). The regulatory authority should specify the chemical and physical properties to be sampled on the basis of the toxic-forming substances in the overburden and their potential for becoming mobilized under new conditions of acidity and reduction/oxidation (redox) potential.

Surface Water

Minimum baseline surface-water information requires an inventory of surface-water bodies, such as streams, lakes, and impoundments located in the permit and adjacent areas. The inventory must include the name, location, ownership, and a description for each water body identified. It must also show the location of points of discharge into or withdrawal from any of the water bodies, the names of water users, and the quantities of water used by each. In addition, all registered rights to any of this water should be listed.

Minimum surface-water information requirements are stated in the regulations at 780.21(b). This information includes the name, location, and ownership, and description of surface-water bodies in the proposed permit and adjacent areas, approximate rates of usage, flow rates, a measure of total suspended solids, total dissolved solids, pH, total iron, and total manganese. If the geologic and overburden samples indicate the presence of acid-forming materials, then acidity and alkalinity information is also required. The regulations also require a determination of the operation's impact on flooding and streamflow alteration. Therefore, information on floodflows is necessary. The length of record and frequency of sampling for all the baseline information must be sufficient to demonstrate the seasonal variability of measured parameters. Additional information may be required, depending upon the complexity of the hydrologic system and the concerns of the regulatory authority.

Baseflow discharges in streams ordinarily carry little, if any, suspended sediment. The largest suspended sediment concentrations in streams usually result from storm or snowmelt runoff events. On the other hand, the largest dissolved solids concentrations commonly occur during low-flow periods when dilution is minimal. Therefore, in order to adequately determine the baseline sediment concentrations, it is necessary to obtain water samples and corresponding waterflow rates during stormflows, as well as during low-flow periods. It is preferable for the stormflow samples to be obtained during the normal high-flow period of the year. Obviously, samples of low flows in ephemeral streams are not required.

Surface-water quantity with respect to surface mining regulations refers to the excess precipitation that runs off the land surface and refers to ground water after it discharges to the surface along streams and at springs. The surface runoff volumes and rates are a function of storm and watershed characteristics. The occurrence of a particular size and intensity of storm cannot be predicted except in terms of recurrence interval. However, the amount of runoff that results from a particular size of storm can be predicted with reasonable certainty, given the watershed characteristics (specifically, soil type, vegetation type and density, and land surface gradients). Mining, at least temporarily, modifies a number of the watershed characteristics, thus potentially altering the quantity of runoff resulting from a particular size storm, and possibly changing the amount of ground water that discharges into surface streams.

The determination of potential impacts to the surface-water quantity involves defining the streamflow and watershed characteristics prior to mining, estimating how the characteristics will be changed during and after mining, and then estimating to what degree those changes will affect the quantity of water in streams originating on or crossing the permit area and adjacent areas. Site-specific streamflow information is usually not available and may require several years of record to develop. However, adequate baseline flood discharges can usually be estimated from records at nearby stream gages or from regionalized regression equations. (See chapter IV.) Parameters used to characterize baseline watershed and flow conditions must be evaluated to show the seasonal fluctuations of flow rates and water quality.

The number of surface-water evaluation sites needed depends on the complexity of the stream system and the requirements of the regulatory authority. At a minimum, an evaluation site should be located at each point where a stream enters or leaves the permit area. Baseline information may also be needed at

inflow and outflow points on lakes and reservoirs. Flow rates and water quality should be evaluated at each site.

Baseline data must define the current streamflow regime. Flow characteristics for perennial and intermittent streams may be defined by (1) annual mean flow, (2) flow duration, (3) flood frequency relations, and (4) high- and low-flow frequency relations. For ephemeral streams, the flow regime can be defined by (1) annual mean flow, (2) flood frequency relations, and (3) high-flow frequency relations.

Annual mean flow is the mean of the average daily flow occurring during a period of water years. A flow duration curve is a cumulative frequency curve that shows the percent of time during which selected discharges are equalled or exceeded during a given period of time. The curve is a convenient method of studying the range and variations of streamflow and comparing one site with another. It also can be used to extend a short-term station record by comparing it with a nearby long-term station record. The curve is useful in predicting the availability and variability of future flows, provided the curve is fairly representative of long-term flow conditions (usually 10 years or more). Flow duration curves also are useful in studies relating to water supply, sediment yields, and stream pollution (Searcy, 1959).

Frequency curves (flood frequency and high flow frequency) show the average recurrence interval for flows exceeding the of a given peak discharge or average discharges for various consecutive time periods (Riggs, 1968b). High-flow volume and flood frequency relations are needed in the design of all types of hydraulic structures and impoundments (Riggs, 1968a). Low-flow frequency data for a stream are necessary to evaluate its adequacy to supply water (Riggs, 1972). At a minimum, measurement of river stage and water discharge should be made.

A preliminary geochemical evaluation will provide some insight into selecting water-quality constituents that should be monitored before, during, and after mining. However, as a minimum, dissolved solids, pH, total iron, total manganese, sulfate, total suspended solids, and alkalinity-acidity are needed. Temperature, pH, and specific conductance corrected to 25°C should be measured onsite. Discharge should be measured and recorded whenever a water-quality sample is collected. Additional water-quality parameters that have been identified from mining activity in the region may be required by the regulatory authority. Mine operators should coordinate with the regulatory authority on baseline quality parameters prior to data collection. Frequently, the regulatory authority will have identified parameter collection requirements for providing adequate information as a result of existing water-quality standards, water users, and environmental concerns.

Instrumentation for collecting water-quality data will depend on the data to be collected (Guy, 1970, 1977; Guy and Norman, 1970; Porterfield, 1972; Skougstad and others, 1979; Barnett and Mallory, 1971; Thatcher and others, 1977). Water-quality samples must be analyzed using standard methods. Specialized procedures and equipment, such as sediment samplers, may be necessary to ensure that samples collected are representative of the stream cross section and discharge.

CHAPTER IV

PHC METHODOLOGY

A PHC determination provides predictive estimates of the probable hydrologic consequences (impacts) of mining and reclamation activities on the hydrologic balance. This requires the analysis of baseline hydrologic and geologic information and possibly of supplemental information. Neither the Act nor the regulations requires particular types of analyses, nor does either specify a level of detail or accuracy that the analysis must achieve. These may vary according to the hydrologic complexity of the proposed permit area, and to the specific requirements of the regulatory authority.

The general requirements of a PHC determination are that it consider impacts on the quantity and quality of surface and ground waters under seasonal flow conditions on and adjacent to the proposed permit area. The potential impact of mining on water quality is generally of greater concern than the impact on quantity, but this may vary from region to region. For example, in areas of high precipitation, water quantity may not be of particular concern and the evaluation would focus on quality of the water. However, in low precipitation areas, small changes in quantity may significantly affect existing water rights. In this case, quantity as well as quality may be equally important.

The process outlined in Chapter II indicates a two-level analysis. The baseline information is initially analyzed by qualitative means to identify potential adverse impacts. With this information, a reclamation plan is developed. Then, a more sophisticated analysis may be needed to determine whether the adverse impacts will be sufficiently mitigated by the planned reclamation. The results of this second analysis provide the basis for determining whether the project has been designed to minimize impacts to the hydrologic balance and the basis for developing a CHIA.

There are no hydrologic analysis methods that are considered as uniquely "PHC methodology." A method's suitability for a particular PHC analysis is determined by its applicability to the hydrologic system to be analyzed, its capability in providing the desired accuracy, and its acceptability to the regulatory authority. Therefore, PHC analytical methods should be selected on the same bases as would be used to select methods for any other type of hydrologic analysis.

SURFACE-WATER QUANTITY

The streamflow at a particular site consists of baseflow and of surface runoff resulting from precipitation. Baseflows are the result of ground water discharging into the stream. Seasonal flow conditions refer to the broad fluctuation of flows over the course of a year. Peak discharges result from the addition of surface runoff due to rainfall and snowmelt events to the baseflows. Low flow refers to the minimum discharges during the year and is totally the result of baseflow. For ephemeral streams, there is no baseflow component; their flows occur only in response to precipitation and snowmelt events.

Discharge parameters most often included in hydrologic analyses are peak flow frequencies, low-flow frequencies, and mean flow values. Although seasonal

flow conditions generally do not include values from instantaneous peak flows, the regulations require the PHC determination to indicate the impact of the proposed operation on flooding or streamflow alteration. Therefore, some analysis of peak flows is also necessary.

The baseflow and surface runoff components of streamflow are normally analyzed separately. Since baseflow derives from ground water, ground-water methods are used to predict mining impacts to baseflow. The problem of analyzing and predicting surface runoff is normally a two-part process: estimation of runoff volume and the routing of that water to the selected site. The results of the routing takes the form of a hydrograph. There are also direct methods for predicting mean and peak discharges at a particular site. The following is a brief discussion of the different types of methods for analyzing surface flows. Appendix D.1 lists various methods, their advantages, limitations, and data requirements.

Determination of Runoff Volume

This is normally accomplished by subtracting losses (evapotranspiration and infiltration) from the amount of water that falls to the Earth's surface during a precipitation event of a specified magmitude. The amount of evapotranspiration is very small during a storm and is usually considered to be negligible. Both empirical and physically based methods are available for calculating infiltration.

Empirical Methods

The most commonly used empirical methods include the Curve Number method, ϕ-Index method, and Horton's equation. These methods are basically procedures for applying relationships derived from experimental plots to the sites of interest. They usually involve grossly simplified representations of the physical system and may produce large errors at a specific site.

Of the empirical methods, the Curve Number method is the most widely accepted and used in mine permitting applications, despite its shortcomings. The method lumps all losses except evapotranspiration into a single initial abstraction. It correlates rainfall-direct runoff relations as a function of soil type, land use, and hydrologic condition. It was developed for designing water-control structures on croplands and remains best suited for design purposes. Because it is not easily calibrated to actual watershed responses, it is not well suited to prediction of streamflows. Despite recent modifications, its application to large, steeply sloping watersheds is a questionable practice. However, the method is popular because it is relatively easy to use under a variety of field conditions.

Other empirical methods have been largely ignored because they do not adequately represent the infiltration process or because they are difficult to use. Some of the use difficulties may be reduced or eliminated by the capabilities of present-day hand-held calculators and small computers, so that some of these methods may find wider use in the future.

Physically Based Infiltration Methods

These methods are simply mathematical expressions of the physical process (infiltration, in this case), as it is understood. The expressions are conceptually

accurate but are often difficult to solve, requiring indirect solution methods with laborious calculation. The Green-Ampt equation is a commonly used, physically based equation for describing the infiltration process. Its use involves indirect solution methods, and it is usually employed as part of watershed models rather than as a method by itself.

Hydrograph Development

A hydrograph depicts the variation of discharge rate over time at a specified location. The hydrograph shape determines the timing and magnitude of the peak discharge and is a function of how rapidly runoff volume forms (excess rainfall) and conditions of the flow path (time of concentration). For estimating runoff peaks, the hydrograph shape must be assumed because the actual shape is unknown. A common method of developing hydrographs is based on unit hydrograph theory.

The unit hydrograph is traditionally defined as a hydrograph produced by an H-hour duration storm of constant rainfall intensity containing one unit of runoff volume. It is based on the assumptions of a linear and constant time increment system, which means that the principal of superposition can be used to solve the governing equations and that the same unit-hydrograph can be used through the storm's duration. The literature contains numerous unit hydrograph shapes that have been developed and used. Those most commonly used are the triangular hydrograph, Haan's dimensionless hydrograph, and the double-triangle hydrograph. The techniques for developing and using these and other unit hydrographs to develop a runoff hydrograph can be found in most standard hydrology texts. The baseflow hydrograph must be added to this runoff hydrograph to obtain the hydrograph of the total flow past a specific site.

Direct Methods of Estimating Discharges

These methods predict peak discharge quantities directly without computation of a runoff hydrograph. They are generally simpler to use than the hydrograph procedure and may be in the form of empirical procedures or regionalized regression equations. The rational method, Cook's method, Bureau of Public Roads method, TPM method, and the SCS TR55 method are examples of empirical procedures. In general, use of these methods involves plugging factor values selected from tables, graphs, or charts into an equation. The accuracy of results depends on how completely the method factors represent the system and is difficult to verify.

Regionalized methods are usually in the form of regression equations in which the dependent variable is a flow characteristic, and watershed and climatic characteristics are independent variables. Stream channel dimensions have also been used as independent variables. Such equations are most frequently developed to provide the peak discharges of a specified frequency, but they can also be developed to provide mean discharges, low-flow discharges, and runoff volumes. The process of developing regressions also provides a statistical measure of the equation's accuracy. Regionalized regression equations have been developed to estimate peak discharges for all the coal-producing areas of the conterminous States. These are listed in table IV-1. Appendix D.1 provides additional information about each reference.

Table IV.1.--Regionalized flood-frequency methods

Location	Reference[1]
Alabama	Hains (1), McCain (2), Pierce (3)
Arizona	Fogel (4), Osborn and Laursen (5), Roeske (6)
Arkansas	Patterson (7)
Colorado	McCain and Jarrett (8), Livingston (9), Hedman and others (67)
Georgia	Carter and Putnam (10), Golden (11), Price (12)
Illinois	Carns (13), Chow (14), Curtis (15)
Indiana	Davis (16)
Iowa	Lara (17)
Kansas	Jordan and Irza (18)
Kentucky	Hannum (19)
Louisiana	Neely (20)
Maryland	Walker (21)
Massachusetts	Johnson and Tasker (22)
Michigan	Brater and Sherill (23)
Mississippi	Colson and Hudson (24)
Missouri	Hauth (25), Sandhaus and Skelton (26)
Montana	Dodge (27), Johnson and Omang (28), Omang and others (68)
Nebraska	Beckman (29)
New Mexico	Scott (30), Thomas and Gold (31), Scott and Kankler (69)
North Carolina	Jackson (32)
North Dakota	Crosby (33)
Ohio	BPR (34), Kresge and Nordenson (35), Webber and Mayo (36)
Oklahoma	De Coursey (37), Rao and others (38), Thomas and Corley (39), Sauer (40)
Oregon	USCOE (41)
Pennsylvania	Aron and others (42), Flippo (43), Lee and others (44), McSparran (45), Reich (46)
Tennessee	Randolph and Gamble (47)
Texas	Schroeder (48)
Utah	Blakemore and Lindskov (49), Fields (70)
Virginia	Miller (50)
Washington	Cumman and others (51)
West Virginia	Frye and Runner (52)
Wyoming	Craig and Rankl (53), Lowham (54), Wahl (71)
Northeastern U.S.	Armbruster (55), Brewer and others (56), Susquehanna River Basin Study Coordinating Committee (57), Thomas and Benson (58)
Pacific N.W.	Osborn and others (59)
National	Benson (60, Hamilton and Jepson (61), Dawdy and others (62), Fletcher and others (63), Hardison (64), Reich (65), U.S. Water Resources Council (66), Patton and Baker (72), Riggs (73)
Western U.S.	Osterkamp and Hedman (74)

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[1] See Appendix D.1 for additional information.

A major shortcoming of these methods relative to PHC determinations is that they are usually derived with data from relatively undisturbed watersheds and, therefore, generally provide no means for predicting the effects of mining disturbance on the hydrologic balance. They are, however, useful for evaluating premining streamflows and are, in many cases, preferable to the Curve Number method for this purpose.

Physical Watershed Models

The methods discussed above attempt to predict the hydrologic response of an area through cause-effect relationships, or with highly simplified expressions of a hydrologic process. Physically based methods attempt to mathematically depict the various hydrologic processes involved (in this case, surface runoff). If the processes are accurately expressed, then the equations should be applicable to any hydrologic system that is conceptually consistent with the equations and for which there is sufficient data to adequately define the system. In theory, this approach should provide more accurate results than the cause-effect methods.

Physical models simulate watersheds when equations depicting several hydrologic processes are applied interactively over a geographical area. The solution of equations thus configured requires many calculations which are most easily done by an electronic computer; thus, the term "computer model." For surface runoff, the model might consider the effects of infiltration, evaporation, evapotranspiration, and interflow processes on the precipitation falling on the watershed. However, at a given site, some of the processes may be considered relatively insignificant and be omitted. The stresses of mining can be incorporated with relative ease in these models, and their effects can be evaluated at as many locations as desired. In practice, watershed models are not universally applicable but are tailored to the specific conditions of the area being analyzed. Watershed models have been developed to evaluate all aspects of surface- and ground-water quantity and quality. Many of these are listed in Appendix D.1.

SURFACE-WATER QUALITY

Surface-water flows originate from surface runoff and from ground-water discharge into streams. Only runoff quality will be discussed here. The quality of ground-water discharge will be discussed in the ground-water section.

Impacts to the quality of surface waters due to surface mining usually take the form of changes in concentrations of dissolved solids and sediments. With the proper handling of toxic and acid-forming materials and the replacement of topsoil, the problems of increased dissolved-solids concentrations and acidity in surface runoff should be minor at most mines. Erosion and sedimentation may be the greater problem and may, in fact, cause increased dissolved solids concentrations. Determinations to be made for the PHC include the maximum concentrations and total loads of dissolved solids and sediments to be expected in runoff from disturbed areas, and the amount of time after reclamation is completed until these concentrations are reduced to required levels.

Total Dissolved Solids and Acid Drainage

High concentrations of dissolved solids can seriously decrease the value of water to its users. Irrigation water high in salts reduces crop yields, and dissolved solids can corrode farm and industrial equipment. In drinking water supplies, dissolved solids have negative health and esthetic effects. Acid mine drainage is one of the most serious water quality problems in the Eastern and Midcontinent coal basins. Acid solutions are produced by weathering of pyrite, marcasite, and iron disulfides found in geologic materials normally associated with coal mining. As the pH of receiving waters decreases, other minerals are dissolved and transported. These include arsenic, mercury, lead, zinc, cadmium, aluminum, copper, chromium, nickel, and other trace elements (Wewerka and others, 1976).

During actual mining and for some time after topsoil is replaced and vegetation is becoming reestablished, dissolved solids concentrations may reach elevated levels from spoil or subsoil contamination because new mineral surfaces are being exposed to air and runoff water on an almost continual basis. Once vegetation is reestablished and stirring of surface soil materials stops, the supply rate of minerals readily available at the land surface for solution and transport should decrease to premining levels at a rate proportional to the amount of precipitation received. However, erosion is also a particle-surface exposure mechanism, and if erosion rates are higher than premining levels, dissolved solids concentrations of surface runoff may remain at elevated levels for a longer period.

Methods for identifying potentially toxic and acid-forming materials are discussed in the sections on collection of geologic and overburden information (Chapter III). These procedures and tests should indicate the maximum dissolved solids concentrations to be expected. They may also indicate how much water is needed to flush the mobile constituents from a given quantity of soil. With this information and the average amount of precipitation received, the amount of time necessary to reduce dissolved mineral concentrations to desired levels can be estimated.

Models are also available for predicting concentrations of dissolved solids in surface runoff. These range from simple routing procedures to complex computer models which generate water, chemical, and sediment volumes, and route them to various points in the stream system. Some produce continuous simulations in time; others simulate individual storm events; and some can provide both types of simulations. A routing procedure is needed to combine the concentrations of surface- and ground-water components of flow in receiving streams. Tables IV-2 and IV-3 list methods for predicting probable impacts due to acid formation and total dissolved solids, respectively. Table IV-4 lists watershed models with water quality and/or sediment yield routines. Additional information about all these methods can be found in Appendix D.1.

Table IV-2.--Methods for estimating acid mine drainage impacts

(See Appendix D.1 for additional information)

Method	Number of parameters measured	Estimated accuracy[1]
Chadderton (83)	5	G
Morth and others (84)	10	G-VG
Caruccio and others (85)	3	NV
Jaynes and others (86)	10	NV
Yeasted and Shane (87)	3	NV

[1]P = Poor, G = Good, VG = Very Good, NV = Not Verified.

Table IV-3.--Methods for estimating total dissolved solids yield

(See Appendix D.1 for additional information)

Models	Solution method	Number of parameters measured	Estimated accuracy[1]	Regional applicability
Bauer and others (95)	Mass balance	6	F-G	Colorado
Parker and Norris (96)	Mass balance	4	F-G	Colorado and Utah
Van Voast and Thompson (97)	Saturated paste extract and mass balance	4	F	Tongue River
Woods (98)	Mass balance	12	G	Tongue River
Lystrom and others (99)	Regression equation	10	F-G	Susquehanna River
Puente and Newton (100)	Regression equation	6	F	Warrior coal field
Jobson (101)	Mass balance	15	F	Nationwide

[1] F = Fair, G = Good, VG = Very Good.

Table IV-4.--Watershed models with water quality and sedimentation components

(See Appendix D.1 for additional information)

Model	Hydrologic component	Erosion sedimentation component	Other water quality component	Number of parameters measured	Estimated accuracy[1]
TVA SYSIM (103)	SCS CN (77)	USLE (88)	---	28	G-VG
SEDIMOT II (104)	SCS CN (77)	USLE (88) and others	---	100	G-VG
ANSWERS (105)	USDAHL (80) and others	Foster and Meyer (91) Meyer and Wischmeir (1969)	---	28	F-G
TENN-I (106)	SCS CN (77) Double Triangle (79)	ERODE-I	TDS (LOAD-I)	7	F-G
CREAMS (107)	SCS CN (77) and others	USLE (88) and others	Nutrient	29	G
ARM/NPS (108)	SWM (81)	Negev	Pesticide	59	F-G
ACTMO (109)	USDAHL (80)	USLE (88) and Foster	Pesticide/Nutrient	60	NV
PRMS (82)	Parametric Kinematic wave	Hjelmfelt and others (1975)	---	237	G-VG

[1] F = Fair, G = Good, VG = Very Good.

Sediment

The disturbance of the land surface by mining and reclamation activities can significantly increase erosion and sediment yields. The regulations require the PHC determination to include impacts that the operation will have on sediment yield and on suspended solids concentrations of water running off the permit area. Sediment yield is the volume of sediment that passes a designated point on a stream channel over a unit period of time, usually 1 year. The sediment yield is usually less than the hillslope and channel erosion rates occurring in the contributing watershed because some of the eroded material is redeposited before it reaches the sediment yield measurement point. The impacts of mining on sediment yield can be evaluated in two phases: (1) impacts on the erosion characteristics of hillslopes, and (2) impacts on sediment transport characteristics, including any channel erosion.

Hillslope erosion rates are a function of precipitation, surface soil characteristics, hillslope gradient and configuration, and vegetation type and density. Precipitation patterns can be considered a constant for the PHC evaluation. Vegetation cover varies both with slope gradient and orientation and with precipitation, with precipitation being the dominant factor. In high precipitation areas, revegetation and the corresponding reduction of erosion rates will be accomplished in a relatively short time. In low precipitation areas, the reclaimed areas may remain highly erosive for much longer periods because reestablishment of vegetation is slower. The erosion characteristics of topsoil will remain essentially unchanged. However, the breaking up of overburden rock layers in the process of removing the coal can result in significant difference between premining and postmining slope configurations and the corresponding erosion characteristics of the landscape. Although postmining slope gradients may be smaller, the absence of the erosion resistant rock layers leaves the postmining landscape subject to rapid downcutting of stream channel base levels and potentially high general erosion rates. Arid and semiarid areas are particularly susceptible to this problem because vegetation cannot be relied on to counteract the absence of stabilizing rock layers.

Sediment transport rate is a function of the sediment characteristics (particle size and density) and streamflow characteristics, which, in turn, are functions of stream channel shape and gradient. Simply stated, for a given particle-size distribution and density of sediment material, a larger water discharge can carry more sediment, if more is available to be transported. Channel gradient is the most important of the factors controlling stream discharge. Therefore, the overall change of landscape gradients will largely govern the degree of impact of flow characteristics of postmining sediment transport rates. The density of sediments should not change as a result of mining, but the particle-size distribution is very likely to change due to the breaking down of existing material. Therefore, the sediment materials are likely to be more transportable during and after mining. The science of geomorphology involves factors that affect the evolution of natural landscape features, including slope shapes and gradients and formation of type and density of channel systems. Erosion and sediment transport are inherent to the landscape evolution process. Some of the effects of landscape modification that may be helpful in evaluating postmining sediment yields are discussed in Appendix A.

Methods for estimating sediment yields generally fall into two categories: (1) those that estimate sediment yield directly, and (2) those that estimate erosion rates and then determine how much of the eroded material is actually transported to the site of concern.

The most widely used method for predicting soil erosion is the universal soil loss equation (USLE). The USLE is an empirical formula for predicting soil loss due to sheet-and-rill erosion. The equation was developed from over 10,000 plot-years of runoff and soil-loss data, collected on experimental plots of agricultural land in 23 States by the U.S. Department of Agriculture. A detailed description of the equation is given by Smith and Wishmeier (1957) and Wishmeier (1960). The original equation modeled the influence of rainfall intensity, soil erodibility, slope length, plot length, cropping and management practices, and supplemental erosion control measures.

A method for estimating annual sediment yields in the Southwestern United States was introduced by the Sedimentation Task Force, PSIAC (1968). The method consists of tables for assigning index values to each of nine factors delineated as influencing sediment yield. These factors consist of geology, soils, climate, runoff, topography, ground cover, land use, upland and channel erosion, and sediment transport. Index values are assigned on the basis of experience and observations, then totaled to obtain a cumulative sediment yield level. Field tests indicate that PSIAC is fairly accurate for small watersheds in the semiarid Western United States (Renard and Stone, 1982; Shown, 1970). Because factor values can be assigned to simulate postmining conditions, this method may be suitable for PHC determination.

Regionalized multiple regression equations have been developed for predicting annual sediment yields. These equations relate sediment yield to easily measured watershed parameters, such as maximum annual peak discharge, cover density, and watershed area. Examples of multiple regression models include Anderson (1949) for forested watersheds, Strand (1975) and Flaxman (1972) for the Southwest United States, and Lystrom and others (1978) for the Susquehanna River basin. These equations may not be applicable to predicting postmining sediment yields, depending on the conditions from which they were developed. Some commonly used methods of estimating sediment yields are summarized in table IV-5.

GROUND WATER

The PHC determination must evaluate the potential impacts of mining and reclamation upon the quantity and quality of ground water under seasonal flow conditions. Seasonal flow refers to ground-water levels typically occurring in response to fluctuations within the annual cycle rather than in response to isolated precipitation events. Hydrologic, geologic, and mine plan information describing site-specific conditions are needed for input to the PHC method selected to predict impacts to ground-water quantity and quality. Selection of specific predictive methodologies depend on the relevant hydrologic concerns established by the regulatory authority and on the amount of available baseline information.

Table IV-5.--Methods for estimating sediment yield

(See Appendix D.1 for additional information)

Method	Number of parameters measured	Estimated accuracy[1]	Erosion process simulated	Regional applicability
USLE (88)	6	G	Sheet,[2,3] long term	Nationwide
MUSLE (89)	7	G-VG	Sheet, single storm	Nationwide
PSIAC (90)	9	F-G	Sheet, long term	Arid West
Foster and Meyer (91)	7	G	Rill, single storm	Nationwide
Kuh and others (92)	6	G-VG	Sheet, single storm, long term	Semiarid West
Onstad and others (93)	9	G-VG	Sheet, single storm	Nationwide
Roth and others (94)	10	G-VG	Soil erodibility	Nationwide
SEDIMOT II (104)	7	G-VG	Sheet single storm	Nationwide

[1] F = Fair, G = Good, VG = Very Good.
[2] Chemical erosion must be accounted for by another method.
[3] Sediment delivery ratio must be applied.

Hydrologic models ranging from simple empirical equations to complex computer solutions may be used for estimating ground-water impacts. Model fixed-value parameters must be calibrated with site-specific data or data representative of the site. Extrapolation of data from one geographic area to another is acceptable when the similarity of the areas is established and information is available to justify the correlations. Generally, ground-water quantity predictions are made with flow models, whereas ground-water quality analyses require the use of contaminant transport models.

Ground-Water Quantity

An understanding of the rate, direction, and overall pattern of ground-water movement in the several types of aquifer systems encountered in coal regions is essential for predicting impacts to ground-water quantity. Both surface and underground mining have the potential to disrupt and permanently alter the physical characteristics of aquifer systems, such as:

1. Reduction of ground-water availability through the removal of aquifers in the overburden or removal of the coal seam itself.

2. Changes in ground-water storage as measured by water-level declines.
3. Changes in ground-water flow directions.
4. Alteration of stream baseflow conditions.

Seasonal variations in ground-water quantity in the permit and adjacent areas may be defined by measurements of water levels in observation wells, spring discharges, and discharge at streamflow sites upgradient and downgradient from the mining operation. These measurements, in addition to a water well inventory, are important components of the minesite investigation which the applicant must conduct in order to determine baseline conditions. Sufficient hydrologic and geologic information is required for input to the specific method selected for predicting ground-water quantity impacts.

The hydrologic complexity of a site and the significance of the ground-water issues usually dictate the appropriate predictive method needed. The applicant should select a method which accurately reflects site conditions and which has previously been proved effective. It may be adequate to express ground-water quantity impacts qualitatively, with varying degrees of quantitative support. Ground-water levels and flow directions can be described and analyzed mathematically, using partial differential equations. The need for general, broadly applicable approaches to solve flow equations for complex field situations has led to the development of digital models. A partial listing of applicable methodologies for assessing probable hydrologic consequences can be found in Appendix D.1. Other predictive methods can be used by the applicant when approved by the regulatory authority.

If selected for use, a model should be used principally as a tool to synthesize data and to test various hypotheses of how the real hydrologic system may function when certain mining-related stresses are imposed on it. The greatest limitations on the effective use of ground-water flow models are:

1. The basic understanding of physical processes in ground-water systems.
2. The cost of acquiring sufficient field data to accurately describe the characteristics of the ground-water system.
3. The availability of trained personnel.

Ground-Water Quality

Ground-water quality is locally variable, resulting from chemical reactions with the minerals in the soil and the unsaturated and saturated zones. Ground-water quality impacts resulting from mining activities usually involve changes in the concentration of dissolved components rather than the addition of new contaminants. Increased concentrations result from (1) increase in surface area of material exposed, (2) increase in oxidation due to the presence of oxygen, (3) increase in rate of recharge or circulation of water, and (4) increase in solubility due to pH changes.

Potential sources of ground-water quality contamination include acid mine drainage, pit water, waste piles, wastewater from coal processing plants, and spoil placed below the water table. Analysis of potential mining impacts on ground-water quality involves documentation of baseline conditions and must be evaluated on a site-specific basis by conducting a detailed field investigation. Ground-water sampling sites, such as springs and stream baseflow stations, yield information

representative of natural chemical conditions of the water. Chemical analyses from wells and test holes may not reflect existing ground-water conditions, depending upon well construction, completion, and development factors. In order to accurately assess the effect of mining on ground-water quality in the permit area and adjacent areas, upgradient and downgradient sampling should be conducted before, during, and after mining.

The applicant should perform a premining inventory of known water quality problems in the vicinity of the minesite. Water-quality data are available from numerous State and Federal agencies, such as those listed in Appendix C.1. A complete determination of potential water quality degradation requires an assessment of the overburden to be encountered during mining by either acid-base account or leaching tests. The geochemistry of overburden spoils, particularly their acidity or alkalinity, influence the leaching of chemical constituents from spoils into ground water.

The overburden analysis results, along with any existing ground-water quality information, should be combined with a ground-water flow model to estimate the areal extent of projected changes in ground-water quality. Mass balance equations are commonly used to estimate values for the water quality parameters of concern after mixing with undisturbed waters. Mass balance analyses were discussed in the surface-water quality section.

Contaminant transport models are available to the applicant for use in analyzing the movement, mixing, and chemical reactions of contaminated water in the background water and in the soil or rock through which it flows. Because ground-water flow is a major factor affecting the movement of pollutants, contaminant transport models are extensions of ground-water flow models. As a result, a ground-water quality model is only as reliable as the ground-water flow model with which it is coupled. Ground-water quality problems typically encountered in mining situations are more complex than quantity problems. Consequently, ground-water quality prediction models are generally less reliable than those used to estimate ground-water quantity impacts. Appendix D.1 includes some accepted ground-water quality models.

CHAPTER V

PHC REPORT

The report for the probable hydrologic consequences is an important part of the permit application package. The company should make it as complete as possible so that it can be separated from the permit application and still be understood by interested parties. The completeness is important, inasmuch as most of the hydrologic analyses relate to environmental issues. Environmental issues and hydrologic concerns that are unique to each minesite must be covered by the report. A proposed report outline, which should be changed to fit each minesite's unique characteristics, is presented here.

The first major heading of the outline provides for introduction of the mine and a general description of the mine plan and adjacent area. It addresses methods of coal and overburden removal, the surface-water system, the ground-water system, interaction between ground water and surface water, climatic conditions, and geomorphic setting. Appropriate maps and figures should be included to adequately describe the system and meet the regulatory requirements.

The second part covers the both overburden and water baseline data used in the PHC which can be existing data and data collected at the mine for this PHC. Any methods used in data analysis, extrapolation of data, and filling of missing data should be described. This section should contain information on equipment used and how the data were collected and analyzed in both the laboratory and the field. Anything unique or unusual about the data must be described so that the regulatory authority can properly evaluate its accuracy and applicability.

The third part of the report addresses prediction of the probable hydrologic consequences. This section of the PHC report will discuss why particular methods were selected, the data used, any simplifying assumptions made to apply the chosen methods. The following are examples of areas of concern and should be covered in the report where applicable.

(1) Erosional changes
(2) Runoff changes - flood potential
(3) Water quality changes
(4) Drainage network and channel stability
(5) Aquifer modifications or destruction
(6) Land slope stability
(7) The impact on water users from both the quantity and quality perspectives.

RECOMMENDED PHC REPORT CONTENT

The outline presented here is for guidance to the coal mine operators and their consultants in developing a report describing the probable hydrologic consequences for the applicant's mine. The report is intended to be able to be separated from the permit application. The major headings follow the general description contained in Chapter II. Subheadings are to be developed to reflect the work conducted, the hydrologic concerns, the hydrologic balance, the methods used in the assessment, assumptions made, and conclusions reached.

OUTLINE FOR PHC PORTION OF PERMIT PACKAGE

I. Description of the mine plan and adjacent area.

A. Description of the mining operations (maps and narrative):

1. Type of mine (area, contour, underground, etc.).
2. Direction of mining.
3. Overburden handling process.
4. Reclamation program.
5. Identify any problems with overburden based on data developed from analyses of test borings or core sampling from the test drilling program.
6. Describe the geology of the mine and adjacent areas.
7. Overburden chemistry.

B. Description of the surface-water system:

1. Identify all ephemeral, intermittent, and perennial streams; and locate on appropriate maps.
2. Identify all lakes, ponds, and springs; locate on appropriate maps.
3. Collect all available surface-water quality and surface-water quantity baseline data for the general area containing the mine plan and adjacent areas.
4. Identify all water users and locate points of diversion and water quantity and quality needs.

C. Description of the ground-water system:

1. Identify all ground-water wells, seeps, and other ground-water discharge points and locate on appropriate maps.
2. Collect all available ground-water quality and ground-water quantity baseline data for the general area containing the mine plan and adjacent areas.
3. List known aquifers and locate on appropriate maps and cross sections.
4. Describe local and regional components of ground-water flow and their interaction with the surface-water system in the general area containing the mine plan and adjacent areas.
5. Identify all ground-water users and locate wells, etc., with required quantity and quality needs.

D. Description of climatic conditions:

1. Collect existing precipitation data for the mine plan and adjacent areas including monthly and mean annual values.
2. Collect existing monthly temperature and snowfall data for the mine plan and adjacent areas.
3. Collect existing rainfall frequency data for storms for the mine plan and adjacent areas.
4. Calculate premining estimates of the monthly runoff, evapotranspiration, and storage for the mine plan and adjacent areas.

I. Description of the mine plan and adjacent area--Continued.

E. Geomorphic description of the mine plan and adjacent area:

1. Calculate premining soil loss and sediment yield from the mine plan and adjacent areas.
2. Collect data on stream stability during periods of normal and high flow.
3. Identify activities in the watershed containing the mine plan and adjacent areas that may cause erosion.

II. Describe the baseline data collection program (coordinate with regulatory authority).

A. Overburden:

1. Existing data.
2. Sampling program.
3. Baseline data.
4. Evaluation of data and potential impact on hydrology.

B. Surface water:

1. Evaluation of existing data to determine additional data needs.
2. Describe sampling frequency and identify chemical and physical parameters for analysis.
3. Describe how the monitoring points for surface and ground water for proposed mining operations have isolated the site.
4. Describe equipment installed at stations and the parameters for analysis. Discuss any problems encountered.
5. Present baseline data.

C. Ground water:

1. Describe the evaluation of existing data to determine additional data needs.
2. Locate existing domestic wells that may be used to measure piezometric surface and sampled for water quality.
3. Describe any additional wells drilled and developed to obtain water levels, water quality data, and conduct aquifer tests using standard well design and development procedures.
4. Present baseline data.

D. Soil loss and sediment yield:

1. Describe how onsite erosion concerns were identified and predicted.
2. Determine unstable stream and riparian zones by field and map inspection.
3. Identify AVF's if mine is located west of the 100th meridian.
4. Collect the following data to quantify soil loss and sediment yield:
   a. Soils information from published sources.
   b. Water samples during medium and high flow for laboratory analyses of suspended solids.
   c. Field measurements of channel gradients, bank materials, and channel cross sections.

III. Prediction of probable hydrologic consequences of the mining operation.

A. Prediction of mining impacts (surface water):

1. Rationale for selection of the hydrologic technique that allows for prediction of the potential impact based on overburden, mining methods, hydrologic concerns, and reclamation plans. The following are a few examples:
   a. Erosion changes (MUSLE) - (USLE).
   b. Runoff changes (SCS, HEC-1, Rational Equation).
   c. Chemical quality impacts (imperical relationships to overburden, mixing equations that will handle alkaline-acid buffering, etc.)
2. Assess impacts to receiving streams and water users.

B. Prediction of mining impacts (ground water):

1. Select hydrologic techniques that allow for prediction of potential impacts based on chemical analysis of overburden, mining methods, hydrologic resource and reclamation plans. The following are some possible examples:
   a. Loss or gain of ground water by prediction and analysis of water level changes.
   b. Changes in aquifer characteristics.
   c. Chemical change of ground water by solute-transport analysis, correlation with overburden data, etc.
   d. Disruption or elimination of aquifers by removal of the coal resource.
2. Assess ground-water impacts on receiving streams, regional aquifers, and local and regional water users.

C. Predictions of mining impacts on stream morphology:

1. Changes in stream stability.
2. Upland stability problems.
3. Impact on land use, water uses, etc.
4. Effect of permanent structures (ponds, diversions, etc.) on stream morphology.

D. Describe the combined impacts of mining from:

1. Local and regional water users (instream, irrigation, domestic, industrial, etc.).
2. Analysis of impacts on the total hydrologic balance or cycle.

IV. Summary and conclusions.

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APPENDIX A

GEOMORPHOLOGY

Sediment yield characteristics of a watershed are affected by changes in surface runoff, location, and morphology (shape and pattern) of receiving streams. An understanding of the geomorphic system is useful for predicting changes in the hydrologic balance due to coal mining activities and the effect on land use and stream stability.

FLUVIAL MORPHOLOGY

Downstream from its headwaters, a stream gradually increases in size and decreases in channel gradient. The relative importance of erosion and transport processes also changes from head to mouth. In the headwaters area, erosional processes dominate, and little sediment is stored along channel banks. The channel width and depth are controlled by outcrops of bedrock or by large boulders, causing stair-stepped longitudinal profile. Downstream, sediment transport processes dominate, and large amounts of sediment are stored along alluvial stream systems. Alluvial channel geometry (width, depth, and slope) for undisturbed streams is in semiequilibrium between water and sediment discharge.

A given reach of river is stable if the geometry of the cross section and the channel slope remain essentially unchanged over time. If the streambed is being eroded, the bottom level elevation is decreasing, and the channel is said to be degrading. If sediment is being deposited in the stream channel, the bottom elevation is increasing, and the channel is said to be aggrading.

Alluvial stream channels have been classified according to pattern, shape, longitudinal profile, character of bed and banks, and physiographic location (Schumm, 1977). Initial simple descriptive classifications of pattern have been replaced by classifications based on quantitative relationships that usually distinguish straight, meandering, and braided reaches according to measurements of channel slope, sinuousity (stream length divided by valley length), sediment load, and channel shape. (See fig. A-1.) In general, when compared to other alluvial stream types, braided streams have higher gradients, sediment loads, channel width to depth ratios, and finer sediment. Although each pattern can be stable under a given set of conditions, the most common stable channel pattern for an alluvial stream channel is a meandering one.

Many of the stream channels in coal mining areas are bedrock controlled or a combination of bedrock-controlled and alluvial channels. Mining through a bedrock-controlled channel can cause serious problems because the erosion-resistant bedrock material is replaced by spoil, which is generally homogeneous and highly erodible. Improper reconstruction of drainages in bedrock-controlled areas may lead to serious erosion and siltation problems.

Any changes imposed on a watershed (from natural or manmade causes) may change the watershed's form and stability. By changing slope or by overloading a stream system with sediment, it is possible to change from a relatively tranquil and easy to control meandering stream to a braided form, which varies rapidly with

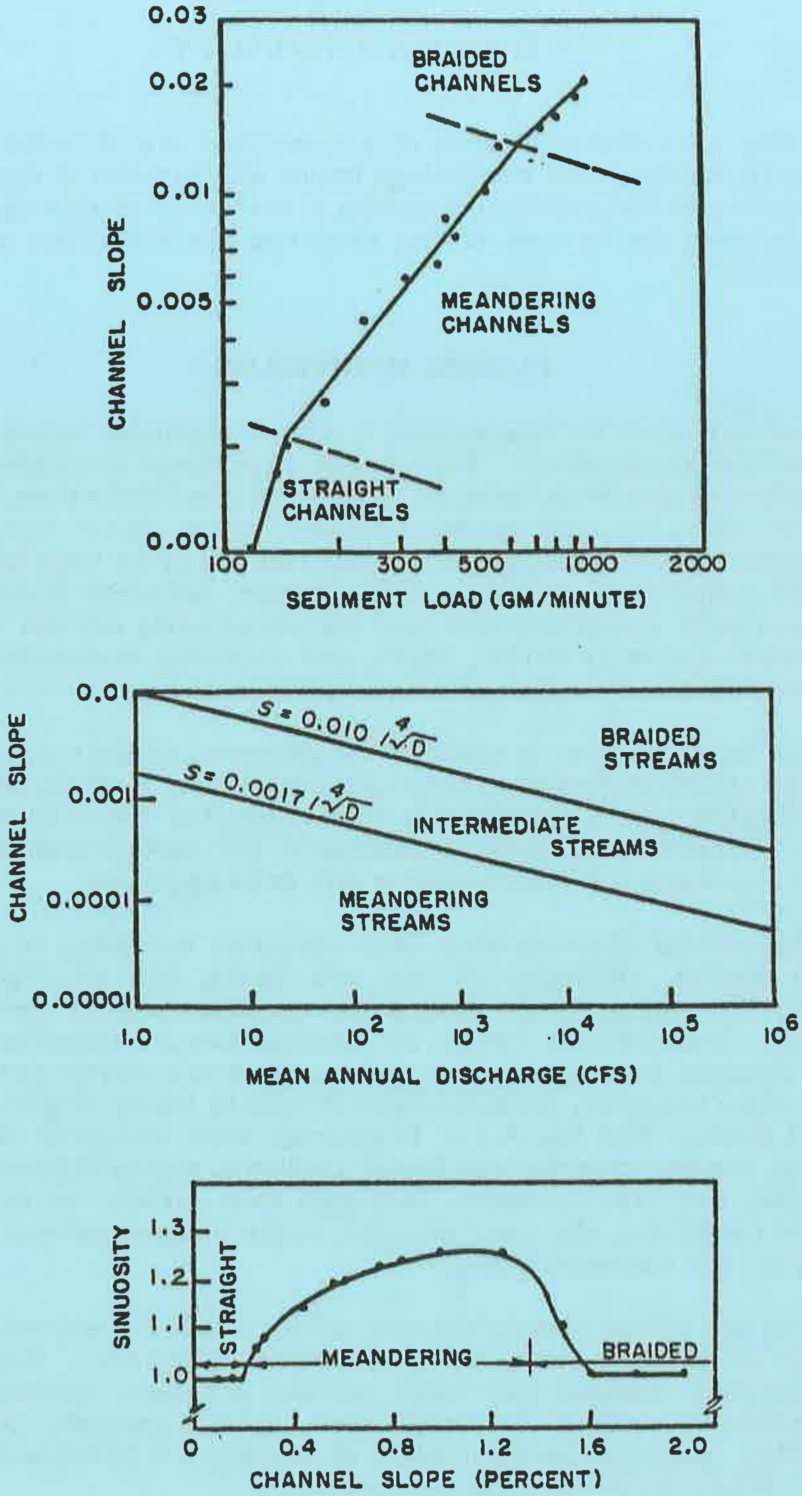

Figure A-1.--Description of channel pattern for alluvial channels (top and middle, Schumm and Khan, 1972; bottom, Schumm, 1977).

time, has high velocities, is subdivided by sandbars, and carries relatively large quantities of sediment. The opposite form change--from braided to meandering--could also occur as a result of a decrease in channel slope, a decrease in sediment load, or a reduction of flood peaks.

Coal mining and reclamation practices may directly or indirectly alter stream channel form and processes. Direct effects result from the physical disturbance of the stream channel (bank stabilization, channel realignment, vegetation changes along the channel banks, stream channel reconstruction, etc.) Indirect effects result from changes on runoff and sediment yield from the contributing watershed, which, in turn, cause changes in channel geometry, channel pattern, and slope. Indirect effects occur because the gradient, channel geometry, and channel pattern of alluvial channels try to adjust to new equilibrium conditions for runoff and sediment. Table A-1 identifies potential indirect effects resulting from changes in runoff and sediment yield. Several examples follow that illustrate possible situations from coal mining activities.

Table A-1.--Potential channel adjustments in alluvial stream channels

(Modified from Schumm, 1977)

Change	Width	Depth	Gradient	Sinuosity
Increased discharge	+	+	−	
Decreased discharge	−	−	+	
Increased sediment load	+	−	+	−
Decreased sediment load	−	+	−	+
Increased discharge and increased sediment load	+	±	±	−
Decreased discharge and decreased sediment load	−	±	±	+

+ indicates increase in variable.

− indicates decrease in variable.

Sedimentation pond discharge can be the primary factor affecting streamflow characteristics in small streams draining active coal-mined basins. Figure A-2 shows a set of storm hydrographs for two streams in eastern Kansas. Station 7 was on a stream unaffected by mining, and Station 5 was on a stream where a sedimentation pond was used. Generally, sedimentation ponds redistribute storm runoff by decreasing peak streamflows and increasing baseflow. The reduction in peak discharge due to a sedimentation pond with an open principal spillway is limited by the discharge capacity of the outlet. (See fig. A-2b.) Draining of sedimentation ponds can cause a short-term increase in water and sediment discharge. (See fig. A-2c.)

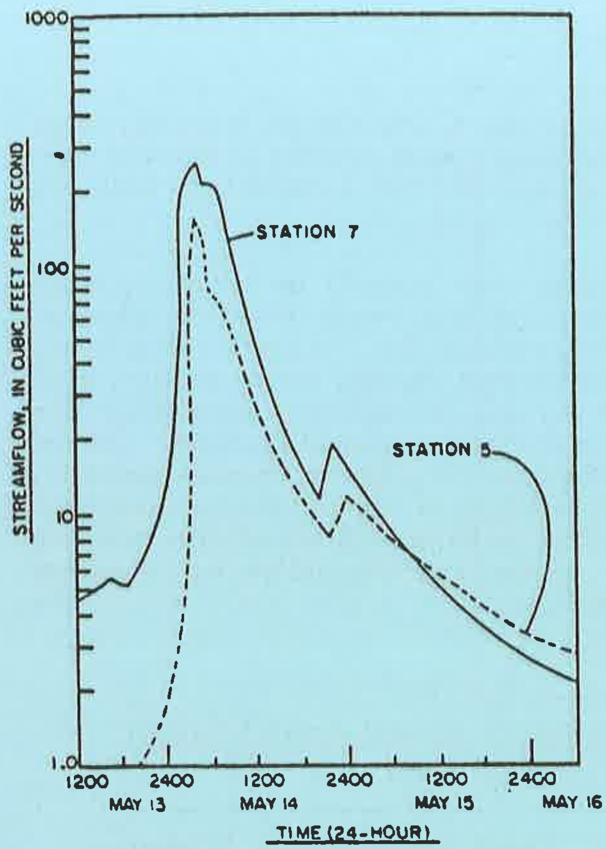

Figure A-2a.--Comparison of storm hydrograph when outlets of sedimentation ponds upstream from station 5 were closed (Bevans, 1984).

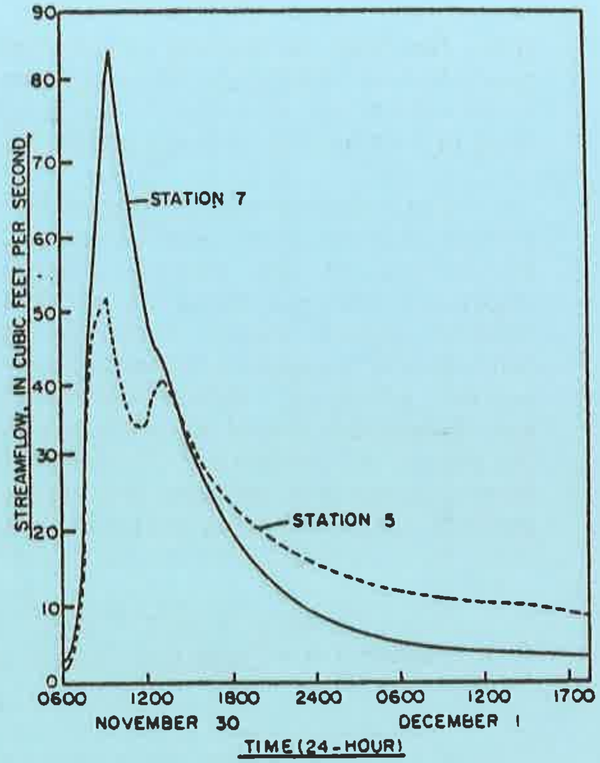

Figure A-2b.--Comparison of storm hydrograph when outlets of sedimentation ponds upstream from station 5 were open (Bevans, 1984).

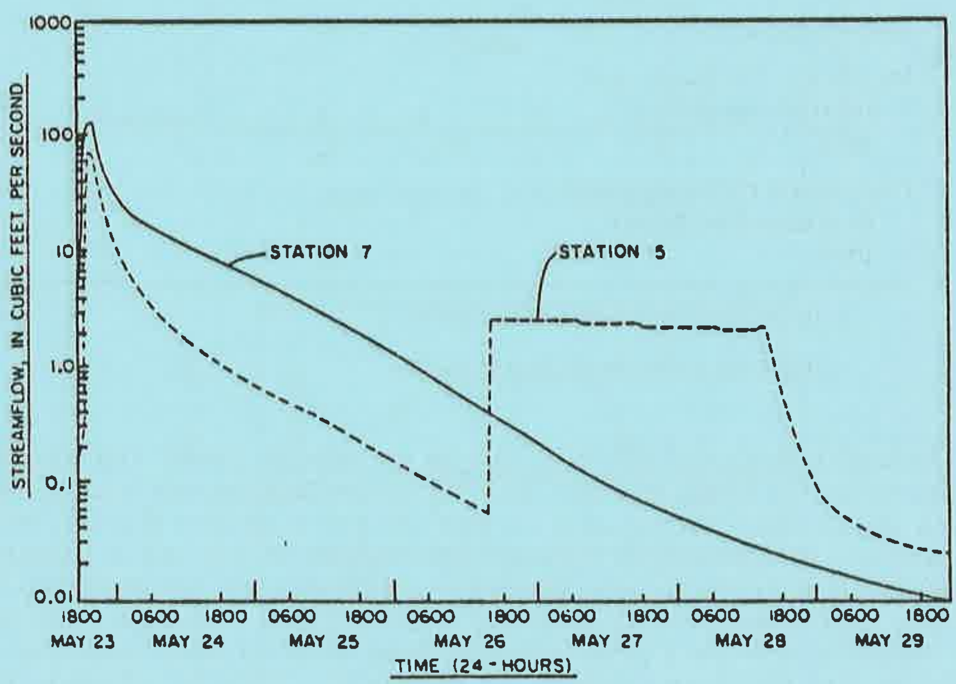

Figure A-2c.--Comparison of storm hydrograph showing effect of draining sedimentation ponds upstream from station 5 (Bevans, 1984).

The effects of the pond will be to decrease water and sediment discharge downstream. Thus, the slope may increase while the width, depth, and meander wavelength may decrease. If the sedimentation pond is allowed to stay in place long enough for the channel to stabilize under the new geomorphic conditions, a new round of degradation (channel cutting) may occur after the pond is removed and higher peak flows return.

SLOPE MORPHOLOGY

Erosion can be minimized by planning earthwork activities on the basis of such things as a knowledge of erosional characteristics of the postmining topography. Slopes are directly affected by mining activities, inasmuch as surface mining results in total removal and rebuilding of the land surface. The combined effects of loss of vegetative cover from stripping activities, compaction of soil by heavy equipment, and increase of slope steepness in and near mining pits can result in extremely high rates of erosion.

In the permit application package, the applicant should provide sufficient information and analysis to demonstrate to the regulatory authority that the reconstructed slopes are stable. According to Curtis and others (1965), the principal features of the landscape which characterize a site and are necessary in its description are:

A. The form of the surface, the surface in plan, and the surface in profile.
B. The microrelief features of the surface.
C. The aspect (direction the slope is facing) of the site.
D. The height of the site above sea level.
E. The relative relief of the site in the local setting.

All these features can be shown on a series of premining and postmining topography maps and range diagrams. This information should be provided in addition to the engineering stability analysis required under 30 CFR 816.

Several authors have documented the importance of designing the postmining topography with slopes that are concave upward or with complex slopes (convex in the upper reaches and concave in the lower reaches). Meyer and Kramer (1969) found that a concave profile will erode less, produce less sediment, and change shape less than a uniform, complex (upper half convex and lower half concave) or convex slope. Gregory and Walling (1973) further documented that many natural long slope profiles are actually composed of one or more segments which are concave upward. For further information on slope morphology, the reader is referred to either of these authors.